2011

Quantification of Agricultural Drought for Effective Drought Mitigation and Preparedness: Key Issues and Challenges

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Published in Agricultural Drought Indices: Proceedings of an Expert Meeting, June 2-4, 2010, Murcia, Spain, pp. 13-21, edited by M. V. K. Sivakumar, R. P. Motha, D. A. Wilhite, and D. A. Wood (Geneva: World Meteorological Organization, 2011).

Quantification of Agricultural Drought for Effective Drought Mitigation and Preparedness: Key Issues and Challenges

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Abstract

The goal of the WMO Expert Meeting on Agricultural Drought Indices was to move forward in the selection of a single drought index that would be used worldwide in the assessment of agricultural drought and its severity. This chapter discusses the challenges in identifying a single index to accomplish this task. Given the complexities of drought and its diverse sectoral impacts, this is a formidable task. However, highlighting the key issues and challenges and recognizing a process or methodology to move the science community forward to achieve aspects of this goal would be a critical step forward. As the next step, identifying a series of alternative approaches to characterize agricultural drought in various settings depending on available data and local capabilities would be an important achievement. Ultimately, all countries should continue to work toward implementing a composite approach in which multiple indices and indicators are used to characterize agricultural drought, its severity, and impacts.

Introduction

Drought is a normal, recurring feature of climate; it occurs in virtually all climatic regimes. It is a temporary aberration, in contrast to aridity, which is a permanent feature of climate and is restricted to low rainfall areas. Subhumid, semiarid, and arid regions are especially drought prone because these regions are often characterized by highly variable interannual precipitation. Agriculture in these regions is frequently quite tenuous, even in normal years, but it is especially vulnerable in below-normal years. Even in more humid climatic zones, drought is often a common feature of the climate, so agriculture is one of the key sectors affected by drought. The agricultural sector would be a primary beneficiary of improved drought monitoring, early warning, and decision-support tools that would reduce the impacts of drought on society and the environment.

Water scarcity is receiving increasing attention and is often confused with drought. Water scarcity can be defined in many ways, but for the purposes of this paper, it is equated with an excess of water demand over available supply (non-sustainable development). It can result from a series of factors, including prevailing institutional arrangements, prices, and the overdevelopment or overallocation of available water resources. Some of the key indicators of water scarcity are the mining of groundwater, increasing conflicts between water use sectors, streams becoming intermittent or permanently dry, and the degradation of land resources. Water scarcity may also be a product of affluence or the expectations of supply in excess of that which is commonly available, or an alteration of supply, such as may be associated with climate change (i.e., increased temperatures, decreased precipitation).

Drought is the consequence of a natural reduction in the amount of precipitation received over an extended period of time, usually a season or more in length, although other climatic factors such as high temperatures, high winds, and low relative humidity are often associated with it in many regions of the world and can significantly aggravate the severity of the event. This natural reduction of precipitation may lead to a situation where supply is insufficient to meet the demands of human activities and the environment. The result is a series of cascading impacts in a wide range of economic sectors and the environment. Drought is also related to the timing (i.e., principal season of occurrence, delays in the start of the rainy season, occurrence of rains in relation to principal crop growth stages) and the effectiveness of the rains (i.e., rainfall intensity, number of rainfall events). Thus, each drought episode is unique in its climatic characteristics. Many of the world's drylands are characterized by the seasonality of precipitation, a characteristic that complicates water management because of the need to store surface water during the rainy season for use during an extended dry season by agriculture and other sectors.

Drought as a Natural Hazard

Drought differs from other natural hazards in several ways. First, since the effects of drought often accumulate slowly over a considerable period of time and may linger for years after the termination of the event, the onset and end of drought are difficult to determine. Because of this characteristic, drought is often referred to as a *creeping phenomenon*. Climatologists continue to struggle with recognizing the onset of drought and scientists and policy makers continue to debate the basis (i.e., criteria) for declaring an end to drought.

Second, the absence of a precise and universally accepted definition of drought adds to the confusion about whether or not a drought exists and, if it does, its degree of severity. Realistically, definitions of drought must be region and application (or impact) specific. This is one explanation for the scores of definitions that have been developed (Wilhite and Glantz 1985, Wilhite and Buchanan-Smith 2005). Although many definitions exist, many do not adequately define drought in meaningful terms for scientists, policy makers, and other end users. For example, the thresholds for declaring drought are arbitrary in that they are not linked to specific impacts in key economic sectors. These types of problems are the result of a misunderstanding of the concept by those formulating definitions and the lack of consideration given to how other scientists or disciplines will eventually need to apply the definition in actual drought situations (e.g., assessments of impact in multiple economic sectors, triggering drought mitigation programs, drought declarations or revocations for relief or emergency assistance programs).

Third, drought impacts are nonstructural, in contrast to floods, hurricanes, and most other natural hazards. Its impacts are spread over a larger geographical area than are damages that result from other natural hazards. For these reasons, the quantification of impacts and the provision of disaster relief are far more difficult tasks for drought than they are for other natural hazards. Emergency managers, for example, are more accustomed to dealing with impacts that are structural and localized. Because impacts are largely nonstructural, the effects of drought are largely concealed and do not have the visual impact of quick-onset natural hazards such as floods and earthquakes.

Fourth, several types of drought exist, and the factors or parameters that define drought will differ from one type to another. For example, meteorological drought is principally defined by a deficiency of precipitation from expected or “normal” over an extended period of time, while agricultural drought is best characterized by deficiencies in soil moisture, a critical factor in defining crop production potential. Hydrological drought, on the other hand, is best defined by deficiencies in surface and subsurface water supplies (i.e., reservoir and groundwater levels, streamflow, and snowpack). These types of drought may coexist or may occur separately. The existence of different types of drought confuses scientists, policy makers, and the public as to whether or not drought exists and its severity.

These four characteristics of drought have impeded development of early warning systems and accurate, reliable, and timely estimates of severity and impacts and, ultimately, the formulation of drought preparedness plans.

Drought Characteristics and Severity

Three essential elements distinguish droughts from one another: intensity, duration, and spatial extent. Intensity refers to the degree of the precipitation shortfall and/or the severity of impacts associated with the shortfall. It is generally measured by the departure of some climatic indicator or index from normal and is closely linked to duration in the determination of impact. Many indices of drought are in widespread use today, such as the decile approach (Gibbs and Maher 1967, Lee 1979, Coughlan 1987) used in Australia and the Palmer Drought Severity Index and Crop Moisture Index (Palmer 1965 and 1968, Alley 1984) in the United States. A relatively new index that has gained considerable popularity worldwide is the Standardized Precipitation Index (SPI), developed by McKee et al. (1993 and 1995). The SPI has undergone rigorous statistical testing (Guttman 1998) and has been shown to be effective in detecting the early emergence of drought because it can be calculated for multiple time scales. This characteristic lends itself well to the initiation of mitigation actions to reduce drought impacts.

Another distinguishing feature of drought is its duration. Droughts usually require a minimum of two to three months to become established but then can continue for months or years. It is quite common for dryland regions to suffer consecutive drought years, but this may also occur in more humid climates. The magnitude of drought impact is closely related to the timing of the onset of the precipitation shortage, its intensity, and the duration of the event. As droughts extend from one season to another and from one year to another, potential impacts are magnified since surface and subsurface water supplies continue to be depleted and a larger number of users are affected. Frequent and multi-year drought events offer no opportunity for natural and managed systems to recover, a critical problem for fragile arid and semiarid ecosystems.

Droughts also differ in terms of their spatial characteristics. Droughts are regional in nature and may affect millions of square kilometers (Figure 1). Because of drought's long duration, its epicenter shifts from season to season and from year to year. Drought monitoring systems must rely on multiple indicators to adequately identify areas of maximum severity and be able to evaluate how changes in the spatial dimension of drought alter current and future impacts and the activation and termination of mitigation actions and emergency programs.

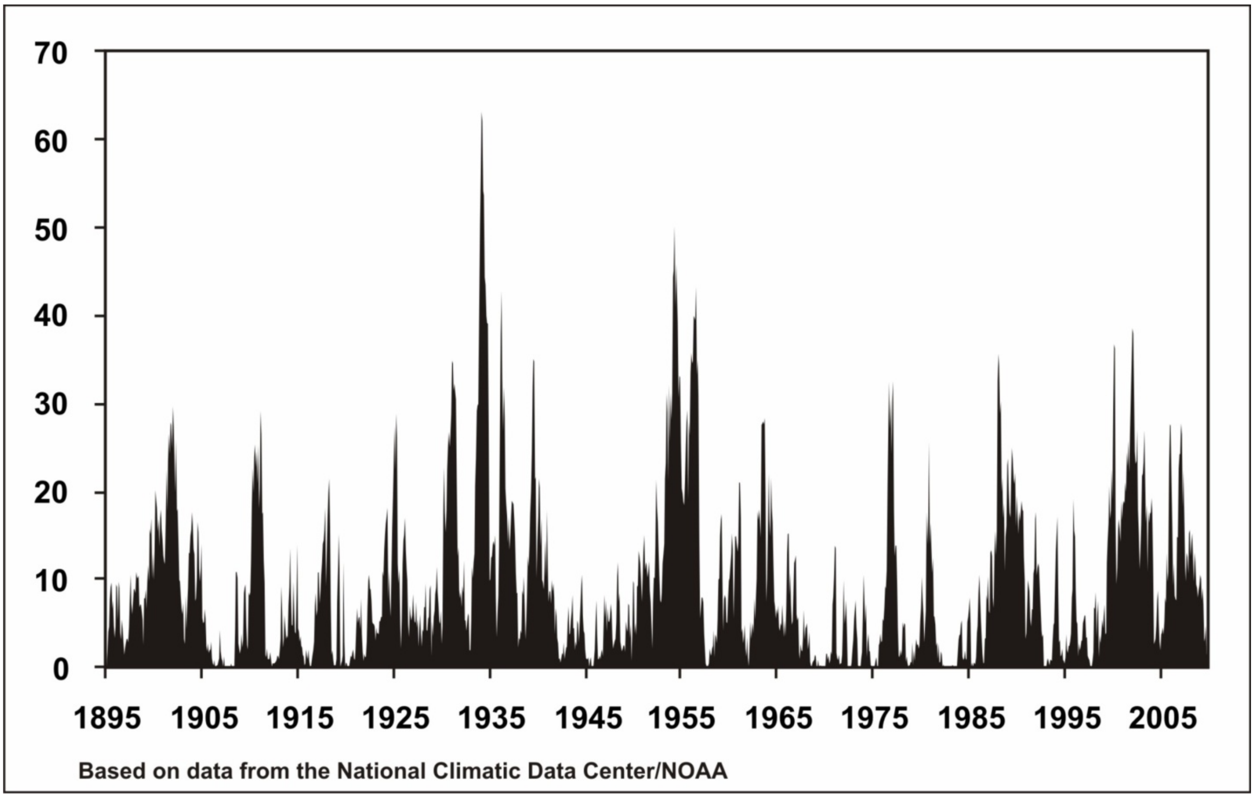

Figure 1. Percent area of the United States in severe and extreme drought, January 1895-May 2010.

Drought Risk and Vulnerability Assessment

Many people consider drought to be largely a natural or physical event. In reality, drought, like other natural hazards, has both a natural and a social component (Wilhite 2009). The risk associated with drought for any region is a product of both the region's exposure to the event and the vulnerability of society to the event. Exposure to drought varies regionally and there is little, if anything, we can do to reduce the recurrence, frequency, or incidence of the event. It is of critical importance that countries develop a comprehensive understanding of the climatology of drought and how the frequency, severity, and duration of these extreme climatic events vary spatially.

Understanding the nature of the hazard helps identify those regions most at risk to drought because of varying degrees of exposure.

In order to have a more complete picture of drought risk, however, we must also understand our vulnerability, which is the product of social factors. Population is not only increasing but also shifting from humid (i.e., water surplus) to more arid (i.e., water deficit) climates and from rural to urban settings for many locations. As population increases, so does pressure on natural resources. People are also forced to reside in climatically marginal, more drought-prone areas. Urbanization is placing more pressure on limited water supplies and the capacity of water supply systems to deliver that water to users, especially during periods of peak demand. An increasingly urbanized population is also increasing conflict between agricultural and urban water users, a trend that will only be exacerbated in the future. Increasingly sophisticated technology decreases our vulnerability to drought in some instances while increasing it in others. Greater awareness of our environment and the need to preserve and restore environmental quality is placing greater pressure on all of us to be better stewards of natural and biological resources. Environmental degradation (i.e., desertification) is reducing the productivity of some landscapes and increasing vulnerability to drought events. All of these factors emphasize that our vulnerability to drought is dynamic and must be reevaluated periodically so that we understand how these changes will affect us and who and what are most at risk for future drought events. We should expect the impacts of drought in the future to be different, more complex, and more significant for some economic sectors, population groups, and regions. The world's dryland areas are most at risk to changes in exposure and the pressures of increasing populations. Improving drought management implies an attempt to use natural resources in a more sustainable manner. This will require a partnership between individuals and government.

Droughts have occurred in the past and they will continue to occur in the future since they are a normal part of climate. The impacts associated with drought may increase because of an increased exposure to the event, increased societal vulnerability, or a combination of the two. For this reason, it is imperative that countries assess their exposure to drought (i.e., historical analysis of drought and its characteristics) and conduct a vulnerability assessment (i.e., create a vulnerability profile) to determine who and what is at risk and why. It is also important to critically assess how exposure to drought may change in the future because of changes in climate variability or climate state and how these changes may affect future vulnerability and adaptation strategies.

Scientific investigations of climate change resulting from an increased concentration of greenhouse gases in the atmosphere suggest that the incidence and severity of meteorological drought may increase for some regions in the future (Pachauri and Reisinger 2007). In recent years, numerous countries have experienced an increased incidence of meteorological drought, but it is unknown at present whether this increase is the result of climate change or a part of normal climate variability. Regardless, this increased frequency of drought has resulted in significant consequences and greater awareness of the need to plan for drought events. Developing countries have been particularly affected because they often lack the institutional capacity to deal effectively with extended drought episodes.

Drought Monitoring and Early Warning

Effective drought early warning systems (DEWS) are an integral part of efforts worldwide to improve drought preparedness. Timely and reliable data and information must be the cornerstone of effective drought policies and plans. Monitoring drought presents some unique challenges because of drought's distinctive characteristics.

An expert group meeting on early warning systems for drought preparedness, sponsored by the World Meteorological Organization (WMO) and others, recently examined the status, shortcomings, and needs of DEWS, and made recommendations on how these systems can help in achieving a greater level of drought preparedness (Wilhite et al. 2000b). This meeting was organized as part of WMO's contribution to the UNCCD. The proceedings of this meeting documented recent efforts in DEWS in countries such as Brazil, China, Hungary, India, Nigeria, South Africa, and the United States, but also noted the activities of regional drought monitoring centers in eastern and southern Africa and efforts in West Asia and North Africa. Shortcomings of current DEWS were noted in the following areas:

- *data networks*—inadequate density and data quality of meteorological and hydrological networks and lack of data networks on all major climate and water supply parameters;
- *data sharing*—inadequate data sharing between government agencies and the high cost of data limit the application of data in drought preparedness, mitigation, and response;
- *early warning system products*—data and information products are often not user friendly and users are often not trained in the application of this information to decision making;
- *drought forecasts*—unreliable seasonal forecasts and the lack of specificity of information provided by forecasts limit the use of this information by farmers and others;
- *drought monitoring tools*—inadequate indices for detecting the early onset and end of drought, although the Standardized Precipitation Index (SPI) was cited as an important new monitoring tool to detect the early emergence of drought;
- *integrated drought/climate monitoring*—drought monitoring systems should be integrated and based on multiple indicators to fully understand drought magnitude, spatial extent, and impacts;
- *drought impact assessment methodology*—lack of impact assessment methodology hinders impact estimates and the activation of mitigation and response programs;
- *delivery systems*—data and information on emerging drought conditions, seasonal forecasts, and other products are often not delivered to users in a timely manner;
- *global drought early warning system*—no historical drought database exists and there is no global drought assessment product that is based on one or two key indicators, which could be helpful to international organizations, NGOs, and others.

Participants of the expert group meeting on DEWS made several recommendations. Those recommendations that pertained directly to early warning systems were that these systems should be considered an integral part of drought preparedness and mitigation plans and that priority should be given to improving existing observation networks and establishing new meteorological, agricultural, and hydrological networks.

Effective drought monitoring requires the integration of a variety of indices and indicators. Indices commonly used to monitor drought and rainfall conditions include the Standardized Precipitation Index, deciles, percent of normal rainfall/precipitation, the Palmer Drought Severity Index, the Surface Water Supply Index, and the Vegetation Condition Index, among others (see, for example, the U.S. Drought Monitor [http://drought.unl.edu/dm/]). Other indicators of drought often used to monitor conditions include soil moisture, snowpack, streamflow, groundwater levels, reservoir and lake levels, vegetation health, and short-, medium-, and long-range forecasts. Remote sensing offers new and exciting opportunities to monitor drought conditions because of higher resolution. These techniques are especially advantageous in regions lacking adequate weather station networks.

Considering the complexity of drought and the many indices and indicators necessary to assess its severity and likely impacts, the most successful approach to date (drought.unl.edu/dm) is the U.S. Drought Monitor (Figure 2). This map is produced weekly through a collaborative partnership between the U.S. Department of Agriculture, the National Oceanic and Atmospheric Administration, and the National Drought Mitigation Center at the University of Nebraska. It incorporates multiple indices and indicators of drought, including impacts, into the assessment process. Although many countries do not have the range of data available to replicate this process fully, any approach that incorporates information beyond precipitation and, perhaps, temperature data is going to provide a more accurate picture of drought severity.

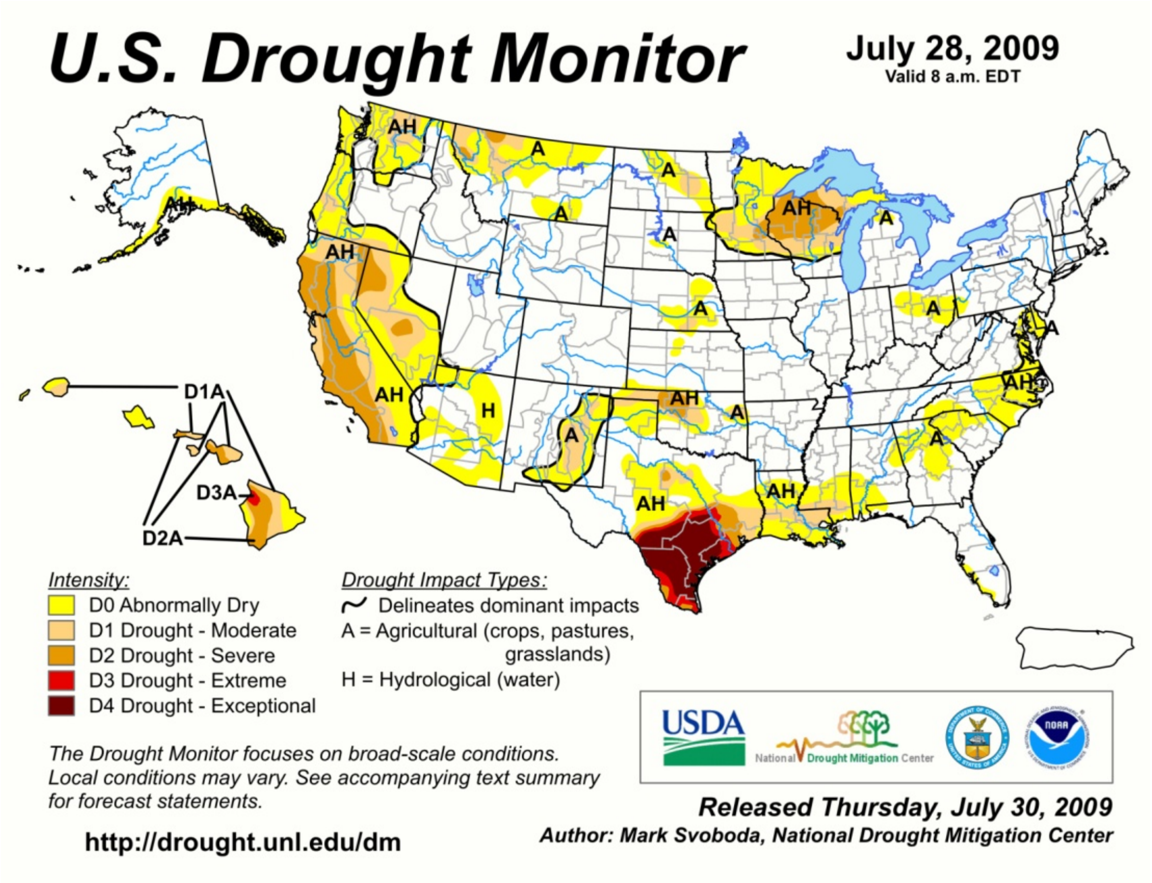

Figure 2. U.S. Drought Monitor for July 28, 2009.

Drought Policy and Preparedness

Article 10 of the U.N. Convention to Combat Desertification (UNCCD) states that national action programs should be established to “identify the factors contributing to desertification and practical measures necessary to combat desertification and mitigate the effects of drought” (UNCCD 1999). In the past 10 years there has been considerable recognition by governments of the need to develop drought preparedness plans and policies to reduce the impacts of drought. Unfortunately, progress in drought preparedness during the last decade has been slow because most nations lack the institutional capacity and human and financial resources necessary to develop comprehensive drought plans and policies. Recent commitments by governments and international organizations and new drought monitoring technologies and planning and mitigation methodologies are cause for optimism. The challenge is the implementation of these new policies, methodologies, and technologies.

One of the trends associated with recent drought events has been the growing complexity of drought impacts. Past drought impacts have been linked most closely to the agricultural sector, reducing the capacity of many nations to be food secure. In both developing and developed countries the impacts of drought are often an indicator of non-sustainable land and water management practices, and drought assistance or relief provided by governments and donors often encourages land managers and others to continue these practices. It is precisely these existing resource management practices that have often increased societal vulnerability to drought (i.e., exacerbated drought impacts). This often results in decreased resilience of individuals and communities and an increased dependence on government. One of the principal goals of drought policies and preparedness plans is to move societies away from the traditional approach of crisis management, which is reactive in nature, to a more pro-active, risk management approach. The goal of risk management is to promote the adoption of preventative or risk-reducing measures and strategies that will mitigate the impacts of future drought events, thus reducing societal vulnerability.

This paradigm shift emphasizes preparedness, mitigation, and improved early warning systems (EWS) over emergency response and assistance measures.

Drought-prone nations should develop national drought policies and preparedness plans that place emphasis on risk management rather than the traditional approach of crisis management, where the emphasis is on reactive emergency response measures (Botterill and Wilhite 2005). Crisis management decreases self-reliance and increases dependence on government and donors. This approach has been ineffective because response is untimely (i.e., post-impact), poorly coordinated within and between levels of government and with donor organizations and NGOs, and poorly targeted to drought-stricken groups or areas. Many governments and others now understand the fallacy of crisis management and are striving to learn how to employ proper risk management techniques to reduce societal vulnerability to drought and therefore lessen the impacts associated with future drought events.

Developing vulnerability profiles for regions, communities, population groups, and others will provide critical information on who and what is at risk and why. This information, when integrated into the planning process, can enhance the outcome of the process by identifying and prioritizing specific areas where progress can be made in risk management.

In the past decade or so, drought policy and preparedness plans have received increasing attention from governments, international and regional organizations, and NGOs. Simply stated, a national drought policy should establish a clear set of principles or operating guidelines to govern the management of drought and its impacts (Wilhite 2000a). The policy should be consistent and equitable for all regions, population groups, and economic sectors and consistent with the goals of sustainable development. The overriding principle of drought policy should be an emphasis on risk management through the application of preparedness and mitigation measures. Preparedness refers to pre-disaster activities designed to increase the level of readiness or improve operational and institutional capabilities for responding to a drought episode. Mitigation actions, programs, or policies are implemented during and in advance of drought to reduce the degree of risk to human life, property, and productive capacity. Emergency response will always be a part of drought management because it is unlikely that government and others can anticipate, avoid, or reduce all potential impacts through mitigation programs. A future drought event may also exceed the "drought of record" and the capacity of a region to respond. However, emergency response should be used sparingly and only if it is consistent with longer-term drought policy goals and objectives.

A national drought policy should be directed toward reducing risk by developing better awareness and understanding of the drought hazard and the underlying causes of societal vulnerability. The principles of risk management can be promoted by encouraging the improvement and application of seasonal and shorter-term forecasts, developing integrated monitoring and drought EWS and associated information delivery systems, developing preparedness plans at various levels of government, adopting mitigation actions and programs, and creating a safety net of emergency response programs that ensure timely and targeted relief.

One thing is certain: continuing to address drought impacts in a reactive, crisis management mode will do little to reduce the impacts of these events in the future. If government continues to "bail out" those people most affected by drought, they will have no incentive to adopt methods that will improve protection of the natural resource base. Should society subsidize poor land managers or reward good land managers? Risk management is aimed at the latter; crisis management, the former. It is precisely these existing resource management practices that have often increased societal vulnerability to drought (i.e., exacerbated drought impacts). Many governments and others now understand the fallacy of crisis management and are striving to learn how to employ proper risk management techniques to reduce societal vulnerability to drought and therefore lessen the impacts associated with future drought events.

Summary

Drought is a creeping phenomenon with no universal definition. Definitions of drought must be region and application or impact specific. Many indices and indicators are available to assist in the quantitative assessment of drought severity, and these should be evaluated carefully for their application to each region or location and sector. To best characterize drought it is critically important to use a combination of indices and indicators since no single one can capture the full severity of a particular drought event. This is an especially difficult assignment for agricultural and hydrological drought.

Data sources are varied between countries, and the development of an effective drought early warning and delivery system requires interagency cooperation to assess drought severity, impacts, and the implementation of appropriate mitigation strategies. The development of systems to deliver that information to decision makers at all levels requires their active participation in the development of decision support tools from the earliest stages of that process.

Drought risk is best defined as a combination of a location's exposure to drought and its vulnerability to drought. Exposure to drought is characterized through an analysis of the historical climatology of a region, including an analysis of trends or changes in climate state and/or its variability. Drought impacts are a key indicator of vulnerability. Therefore, conducting a vulnerability assessment involves an analysis of the historical impacts associated with previous drought episodes. Since societies are constantly changing, vulnerabilities are also likely to change due to increasing population, land degradation, urbanization, technology, and many other factors. Each occurrence of drought for a particular region is layered upon a society with differing vulnerabilities.

Early warning systems are the foundation of effective drought mitigation and preparedness plans. The goal of our meeting on the selection of appropriate drought indices or indicators to characterize agricultural drought was to reach consensus on a single index to accomplish this task. That is a formidable task given the complexities of agricultural drought and the variable institutional capacity of drought-prone nations. At best, we should strive to identify a series of alternative approaches to characterize agricultural drought in various settings depending on available data and local capabilities. As a part of this approach, we should continue to work toward implementing a composite approach (i.e., incorporate multiple indices and indicators) to characterizing agricultural drought.

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